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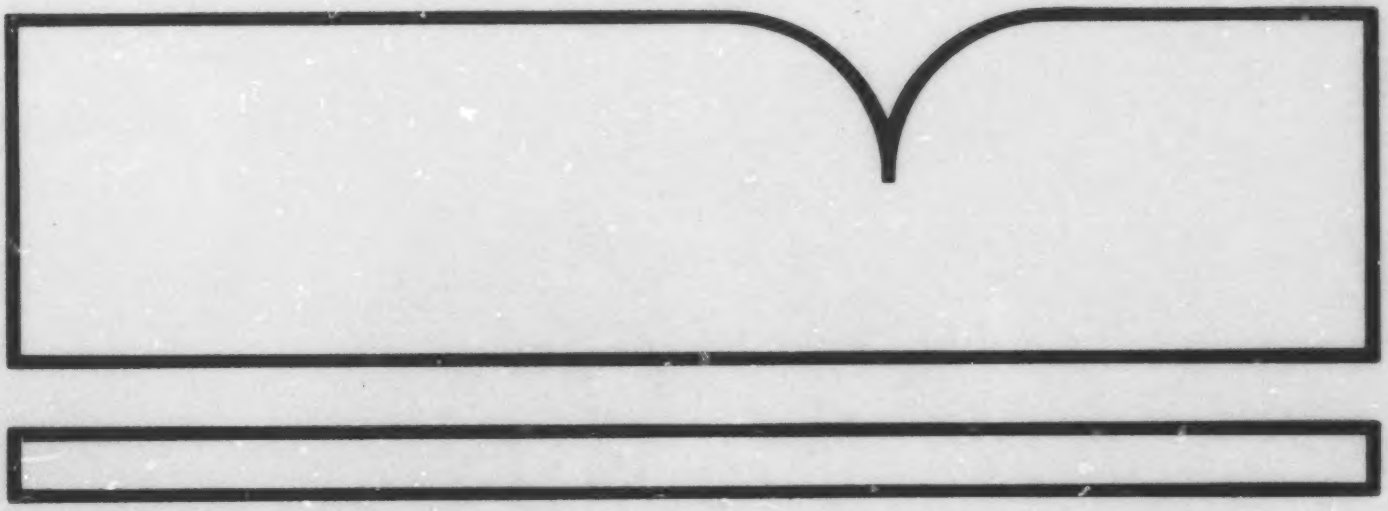

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Grace K. Lemaster[1], Arch Carson[1], and Steven J. Samuels

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9. PERFORMING ORGANIZATION NAME AND ADDRESS
[1]Dept. of Environmental Health, U. of Cincinnati, College of Medicine, Cincinnati, OH 45267; [2]Occupational & Environmental Health Unit, Division of Reproductive Biology & Medicine, U. of California, Davis, CA 95616

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Occupational Styrene Exposure for Twelve Product Categories in the Reinforced-Plastics Industry

GRACE K. LEMASTERS,[A] ARCH CARSON[A] and STEVEN J. SAMUELS[B]

[A]Department of Environmental Health, University of Cincinnati College of Medicine, Cincinnati, OH 45267; [B]Occupational & Environmental Health Unit, and Division of Reproductive Biology & Medicine, University of California, Davis, CA 95616

Approximately 1500 occupational styrene exposure values from 28 reinforced-plastic manufacturers were collected retrospectively from companies and state and federal agencies. This report describes the major types of manufacturing processes within the reinforced-plastics industry and reports on the availability, collection and analysis of historical exposure information. Average exposure to styrene in most open-mold companies (24-82 ppm) was generally 2-3 times the exposure in press-mold companies (11-26 ppm). Manufacturers of smaller boats had mean styrene exposures of 82 ppm as compared to 37 ppm for yacht companies. There was considerable overlap in styrene exposure among job titles classified as directly exposed within open- and press-mold processing.

Introduction

As part of a study on the reproductive health of women exposed to styrene (phenylethylene, vinyl benzene) in the reinforced-plastics industry, historical exposure data were obtained from companies and state and federal agencies. In this industry, styrene, an unsaturated aromatic monomer, is used with unsaturated polyester resins as a cross-linking agent in the manufacture of plastic products. Acute health effects resulting from high-level occupational exposure to styrene include mucus membrane irritation, gastrointestinal symptoms, dermatitis and central nervous system dysfunction.[1-6] In addition, recent occupational studies have suggested an association between styrene exposure and chromosomal aberrations in workers and their offspring, an increase in spontaneous abortions in women workers and other health problems.[7-9] This paper reports on the availability of historical exposure information. Differences in exposure by job title, product and process category are discussed.

Description of Study Plants

Thirty-six fibrous glass-reinforced-plastic manufacturers volunteered as study participants. An on-site survey of each facility was made to obtain a detail understanding of the manufacturing process. An industry survey form, including information on plant construction, description of all processes, and yearly usage of resin and styrene, was compiled. A detailed schematic diagram outlining the processes, departments, job titles and ventilation patterns was constructed for each company.

All companies were engaged in either press (closed) molding, open (contact) molding, or a combination of the two processes. Table I summarizes the processes, produts, average number of products produced, and number of employees for each participating company. Seventeen companies were boat manufacturers. The other open-molding users produced tanks and pipes, truck and parts, tubs and showers, or miscellaneous custom-molded products. Four companies were exclusively press molders and produced trays, containers, electrical boxes, truck and car parts, or compounding materials. Five of the companies performed both open and press molding.

Manufacturing Process

The open-mold processes included hand lay-up, chopper gun operations, filament winding, continuous laminating, and pultrusion molding. Press-mold processes included air preforming, match-metal die, injection molding and the manufacture and use of sheet mold compound (SMC) and bulk mold compound (BMC). Table II summarizes the types of manufacturing processes at each company.

Open (Contact) Mold Processes

The boat manufacturing industry typifies the open-mold fabrication method. First, a single cavity female mold is prepared with a wax. Second, the worker sprays a pigmented resin onto the mold which ultimately appears as the outer "painted" surface. The risins contain up to 40% styrene by weight. Up to 10% of the styrene monomer may be released into the atmosphere during application and curing.[10] During hand lay-up, layers of fibrous glass mat or cloth are impregnated with a liquid polyester resin, applied either by a hand-held spray gun, brush, or hand rolled onto the fibrous glass mat. Alternatively, fibrous glass roving is drawn from a creel, fed through a machine that chops the fiber, and blown at the mold. Finally, a worker hand rolls the mold to remove air.

Filament winding was generally used in the manufacture of tanks and pipes and was the second most common type of open molding. During filament winding operations, continuous strands of fibrous glass pass through a resin bath and are wet-wound on a rotating spool or a mandrel. The mandrel operator constantly checks the band layout and with, often guiding the band by hand, while removing excess resin and air with rollers.

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TABLE I

Description of Manufacturers by Product, Size and Number of Products Produced, Process, and Total Number of Employees

ID	Product	Size (Meters)[A]	Number Produced	Process[B]	Total No. Employees
1	Boat	4.6 - 8.5	624	Open	160
2	Boat	11.3 - 16.2	1180	Open	375[C]
3	Boat	4.6 - 8.5	2600	Open	400
4	Boat	16.8 - 21.4	150	Open	550[C]
5	Boat	5.5 - 7.8	450	Open	86
6	Boat	4.9 - 6.4	2000	Open	73
7	Boat	4.3 - 7.3	2200	Open	93
8	Boat	3.1 - 5.8	560	Open	74
9	Boat	4.5 - 6.1	1000	Open	32
10	Boat	4.5 - 8.5	2500	Open	134
11	Boat	7.9 - 18.9	300	Open	300
12	Boat	12.8 - 14.0	38	Open	91
13	Boat	4.3 - 6.1	4500	Open	170
14	Boat	4.9 - 10.1	300	Open	30
15	Boat	4.6 - 6.1	28	Open	216
16	Boat	4.6 - 7.3	2500	Open	50
17	Boat	10.7 - 13.1	40	Open	151
18	Tank/Pipe	1.8 - 3.7[D]	1380	Open	149
19	Tank/Pipe	1.2 - 5.5[D]	5400	Open	127
20	Tank/Pipe	0.05- 3.7[D]	3100	Open	113
21	Tank/Pipe	0.03- 4.3[D]	19 448	Open	143
22	Tank/Pipe	0.36- 3.4[D]	2308	Open	189
23	Tub/Shower	1.5 × 2.0	62 500	Open	86
24	Tub/Shower	1.5 × 2.0	44 000	Open	98
25	Tub/Shower	1.5 × 2.0	34 000	Open	82
26	Truck Parts	1.5 - 4.6	5672	Open	50
27	Truck Parts/ Buildings	0.31- 3.1	5720	Open	139
28	Truck Parts/ Bath/Tanks	0.61- 4.3	100 000	Both	65
29	Truck Parts/ Trays/Shields	=< 1.5	180 000	Press	210
30	Car Parts/ SMC	=< 1.5	46 800	Press	806
31	Panels/Rods BMC	Varies[E]	6×10^6kg[F]	Both	268
32	Forms/Panels Domes SMC	Varies[E]	6×10^6kg[F]	Both	244
33	Panels/ Tractor Tops	0.9 - 1.8	100 000	Both	177
34	Trays/ Containers	=< 1.0	1×10^6	Press	159
35	Fans	0.92	9240	Both	37
36	Electrical Box	< .5	30×10^6	Press	166

[A]Includes a range of sizes between values
[B]Open mold: press mold: Both = open and press mold
[C]Approximate number provided by Unemployment Bureau
[D]Dimensions of tanks and pipes given in diameter
[E]'Varies' indicates the products were in multiple, not easily defined sizes
[F]Company had units based upon (kg) produced

During pultrusion molding, continuous filaments are drawn through an orifice which distributes encapsulating resin. A dielectric preheat unit provides heat throughout this operation and a heated die completes the cure. Rods and tubes are the primary products made by pultrusion. Continuous lamination operations are semi-automated techniques producing large flat panels. Fibrous glass mat or frabic is automatically drawn through a risin bath and pressed between two cellophane sheets. The mat is then squeezed through large rollers to remove excess resin. Because the processes are semi-automated, the worker has minimal exposure compared to hand lay-up operations.

Press (Closed) Mold Processes

Match-metal die was the most prevalent form of press molding operation. The operator either places a fibroug glass mat

between male and female dies and pours resin on top, or uses a semi-wet pre-weighed mixture of resin and fibrous glass. The press opens, allowing vapor emission. At this point, any free styrene is residual unpolymerized styrene. Injection molding used at only two companies is essentially a closed-mold, very-low-exposure operation. Polystyrene pellets are dropped from hoppers into a barrel, where the plastic is heated. A ram forces the hot plastic from the barrel into a mold. Air preform fabrication methods were used in four companies. Chopped strands and resin are sprayed onto a rotating screen mold. The spray may be controlled automatically of hand-held. The "preform" is then ovenbaked and removed hot by the worker and allowed to air-cool.

Six companies manfuctured bulk mold compound (BMC) and/or sheet mold compound (SMC). BMC and SMC contain resins, fillers, pigments, and catalyst blended into a wet material. During bulk compounding, chopped fibrous glass is added. Resin is usually pumped directly into the mix, but other ingredients, including styrene, may be added either manually or automatically, depending on the plant. During sheet-mold compounding the resin-paste mix is moved either manually or automatically to the SMC machine. Here, the paste is transferred to the resin troughs, mixed with chopped glass and pressed between two plastic sheets. Both sheet and bulk mold compound are used in match-metal die operations.

Thus, for this study, there were two major forms of reinforced-plastics processing: open and press molding. The most prevalent form of open molding involved hand lay-up and chopper-spray-gun operations. At press mold processors, match-metal die operations were most commonly found.

Collection and Classification of Exposure Data

The first step in assessing the effects of an exposure is the identification of processes with exposed workers. NIOSH health hazard evaluations of the reinforced-plastics industry and other published papers were examined to identify the processes with the highest styrene exposures. Names of companies involved in these high-exposure processes were obtained from published lists and industry sources. These

TABLE II

Resin Consumption and Type of Molding Process by Company

COMPANY	Resin kg×10³	Chopping Operators	Hand Lay-Up	Continuous Laminator	Filament Winding	Pultrusion	BMC	SMC	Air Preform	Match Metal Die	Injection Mold
1	0.6	X	X								
2	6.7		X								
3	6.8		X								
4	3.7		X								
5	2.8		X								
6	2.2		X								
7	5.2	X	X								
8	1.1	X									
9	0.9	X	X								
10	4.5	X	X								
11	6.1	X	X								
12	0.8	X									
13	5.6	X									
14	0.5	X	X								
15	4.5		X								
16	2.2	X	X								
17	1.4		X								
18	21.0	X			X		X	X			
19	12.0	X			X						
20	2.3	X	X			X					
21	5.9	X	X		X						
22	34.0	X			X						
23	10.9	X	X								
24	10.5	X	X								
25	7.8	X	X								
26	2.7	X	X								
27	2.1	X	X								
28	1.4	X	X							X	
29	1.1							X	X		
30	33.1							X		X	X
31	18.4					X	X			X	
32	7.3	X	X	X				X	X	X	
33	0.8	X								X	
34	3.4						X	X	X	X	
35	1.1	X	X						X	X	
36	10.8								X	X	

TABLE III

Listing of Styrene Values by Source, Year(S) Collected and Total Number of Samples for Each Company

ID	SOURCE[1]	YEAR(S) COLLECTED[2]	COMBINED NO. OF SAMPLES
1	S	75, 77	17
2	S,F	76, 78	46
3	C	75	10
4	-	-	-
5	F,C	78(2)[2]	25
6	S	75, 77	15
7	F,C	76, 79	45
8	C	81	2
9	-	-	-
10	F	78	140
	C	78(2), 79(2), 80	
11	C,F	75, 78	121
12	-	-	-
13	-	-	-
14	-	-	-
15	S	78, 79	18
16	-	-	-
17	S,F,C	72, 79, 80	22
18	S,F,	69, 72	124
	C	74(2), 75(2), 76(2), 77(2), 78(2), 79(2), 80(2)	
19	C	77, 78(2), 79(2), 80(2)	63
20	-	-	-
21	C	76, 79	22
22	C	72, 73(2), 74, 75(2), 76(2) 77(2), 78(2), 79(3), 80(2), 81	173
23	C	74, 77(2), 78, 80	19
24	C,F	77(2), 79	28
25	C	77(2), 78(6)	103
	S	79(4)	
26	-	-	-
27	C	78	15
28	S	78	10
29	F	74, 78	14
	S	78	
30	C	75, 76(5), 77(5), 78, 79(3),	212
	S	80	
31	C	77, 78(3), 80	47
	S	75, 76	
32	C	79	21
	S	76(2)	
33	F,S	78, 79(3)	93
34	F	78	94
	C	78, 79	
35	S	77, 79	3
36	S	77	10

[1]S=State OSHA or state health/labor agencies
F=Federal (NIOSH or OSHA)
C=Company

[2]The number in parentheses represents the number of times samples were collected in any one year.

companies were then individually contacted. Thirty-six agreed to participate, and each was asked to make personnel records available for the identification of exposed workers.

The next step in a study attempting to document past exposures of workers is creation of job categories identifying occupational exposures. In our study, a walk-through survey was conducted at each participating company. On the basis of this survey and after discussion with company staff, exposure categories were established.

To evaluate worker exposure to styrene, industrial hygiene information was requested from three sources, the company, and state and federal agencies. In the U. S., upon request, the Freedom of Information Act requires the release of industrial hygiene survey records collected by federally funded agencies. A listing of those agencies potentially having exposure information was obtained from two sources: 1) the Occupational Safety and Health Directory published by NIOSH,[11] and 2) a listing of the OSHA On-site Consultation Project Directory.[12] These directories list, by state, names of agencies and the names and titles of key agency personnel with their addresses and telephone numbers. A letter requesting the desired information led to the receipt of data either at no charge or for a small service fee.

Styrene exposure data were available for 28 of the 36 participating companies. The source of the information, number of samples, and years for which data were collected are summarized in Table III. For 15 companies, there were two or more sources of exposure information. Only company-supplied data were available for seven companies and only state-supplied data were available for six. Over 1500 values for workplace air styrene samples were obtained. These samples were originally collected from 1969 through 1981. Ninety-eight percent of these samples were collected using charcoal tubes and analyzed by gas/liquid chromatography. Those obtained or analyzed by other means were not included in any calculations. Most of these analyses were noted as having been performed by standard NIOSH methods. It has been shown that these methods may underestimate true exposure levels.[13] These methods are, however, widely used and are the best comparative measure of exposure for historical data in the United States. Exposure levels are reported here in parts per million (ppm).

The actual individual sample exposure values for individual job titles were available for approximately two-thirds of the data (1000 measurements). For the remaining one-third, only summary values were supplied, *i.e.*, a mean, number of measurements for the mean, and minimum and maximum values. These latter measurements are henceforth referred to as grouped or summary data points. Because of the diverse sources of information, much effort was needed to abstract, organize and computerize these data into a standard format.

Each job title was assigned an exposure intensity of direct contact or indirect contact with styrene. Direct contact was defined as a job activity requiring contact with wet resins containing styrene for 50% or more of the worker's day. Indirect exposure included jobs with less than 50% of a day spent in direct contact with resins containing styrene; these were located in the same vicinity as the directly exposed jobs with primarily "passive" ambient air exposures. Job titles classified as direct exposure for open and press processes are described in Table IV. Indirect exposure included such jobs as assemblers, inspectors, dispatchers, shippers and packers. The job classification of mixer was variably classified as either direct or indirect depending on the amount of time spent compounding resins.

TABLE IV

A Description of Direct Contact Job Titles

Laminators/Rollers	Deposits resin on fibrous glass mat and hand rolls out air bubbles with a roller.
Gelcoater/Sprayer	Sprays resin on molds.
Chopping Machine Operator	Sprays chopped fibrous glass and resin simultaneously through a hand-held applicator.
Mixer	Mixes resin and styrene and other chemicals for use in the fabrication process.
Mandrel Operator	Operates a filament winding machine on which continous wet fibrous glass is wrapped around a rotating mandrel followed by the rolling out of air bubbles.
Press Operator	Places either dry fibrous glass and resin, SMC, or BMC on match metal dies, manually operates press and removes mold.
Special/Bulk Mold Compounder	Formulates mold compounding material by mixing chopped fibrous glass, resin, styrene in a semi-automated vat.
Preformer	Sprays resin and fibrous glass on a rotating mold and/or removes molded piece from the mold.

A major decision involved the choice of categories in which to estimate exposure: job title, company, product, etc. There was no information for eight of the 36 study companies and only limited data for several others. Therefore, we could not assess exposure separately for each company. The data were also too sparse for separate analysis of most job titles.

Preliminary investigation did indicate that there was little variation among job titles once product category, process (open or press), and exposure type (direct or indirect) were considered. Therefore, exposure estimates are presented for product categories classified by process and by exposure type. There were sufficient observations for separate estimation of mean exposure for five job titles.

Methods of Analysis

After the data were entered into a computer file and edited, consideration was given to the correct transformation of the observations. Plots showed that standard deviations and means for each sampling date were linearly related, violating the assumption of equal variances needed for many statistics. Under these conditions, a logarithmic transformation will stabilize the variance.[14] A histogram of the deviations of the log values from their sampling date means, however, was skewed to the left. This skewing was removed by adding 1 ppm to each observation before taking the logarithm. Letting X denote the original measurement in ppm, the transformation $Y=\log_{(10)}(X+1)$ was therefore used in all analyses.[10] For final presentation of results the mean values

TABLE V

Log Scale Variance Components by Product, Process, and Exposure

Product/Process/ Exposure	Company Component (No. of Companies)	Date Component (No. of Dates)	Individual Sample Component (No. of Samples)	Total Variance	Total Standard Deviation
Yacht/Open/Direct	0.0 (3)	0.12 (17)	0.41 (162)	0.53	0.73
All/Open/Direct (excluding Yachts)	0.0 (23)	0.07 (68)	0.13 (591)	0.20	0.45
All/Press/Direct	0.01 (5)	0.05 (13)	0.13 (116)	0.19	0.44
All/Open/Indirect	0.0 (3)	0.05 (8)	0.03 (50)	0.08	0.28
All/Press/Indirect	0.0 (2)	0.0 (4)	0.07 (40)	0.07	0.26

are converted back to the original ppm scale by X= antilog(Y)-1.

The analysis took into account the correlation of observations induced by their hierarchical data structure: measurements made on the same date tend to be more alike than measurements on different dates within the same company, and observations at the same company tend to be more alike than observations at different companies. When this correlation is ignored, the usual standard errors and standard deviations will badly estimate the true variability in the data.[15,16]

To overcome this problem the analysis is based on a variance components model.[16,17] This model decomposes each observation Y into a fixed exposure category effect and into random company, sampling date and individual effects. The company effects vary within exposure categories with variance σ_a^2. Sampling date effects vary within company with variance σ_b^2; individual observations vary within sampling date with variance σ_e^2. The sum of the three, which are called variance components, is the total variance of observations taken at different companies on different dates: $\sigma_T^2 = \sigma_a^2+\sigma_b^2+\sigma_e$. The square root, σ_T, of σ_T^2 is the population standard deviation.

The variance components were estimated from those sampling dates for which individual observations were available. The method of fitting constants in the Statistical Analysis System program VARCOMP was utilized.[18] Where it appeared possible, variance components were pooled across product categories.

Exposure level was estimated by the mean of means (MM) suggested by Samuels, *et al.*[16] This involved taking the means of all transformed observations on each sampling date. Then the average of the sampling date means is calculated for each company. Finally, company means are averaged to produce exposure category means. The MM prevents any one company or sampling date from dominating the estimated exposure level.

The MM was first calculated for individual data. This analysis excluded nearly one-third of the grouped measurements for which only summary means had been reported. To incorporate these grouped observations, a slightly modified MM was calculated. In this modification, the logarithmic transform is applied directly to the summary means at the job title level for each sampling date rather than to the original individual values. The individual data were likewise grouped, transformed and combined with the summary data. In this instance, the difference in the two versions of the MM was trivial. Therefore, only results from this latter data set containing both the individual and grouped measurements were reported.

Standard errors for the MM are based on the estimated variance components. Two standard error intervals (95% confidence intervals) are calculated on the log scale and presented on the original scale. The total variability of individual readings is illustrated with one-standard deviation intervals (log scale) that are converted to the original scale.

Results

Except for yachts, the components of variance did not differ appreciably among the product categories. Therefore, a common set of variance components was calculated (except for yachts) by process, exposure grouping (Table V). Most of the variation was due to individual measurements taken

TABLE VI

Estimated Styrene Exposure by Process, Exposure and Product Category for Grouped Measurements

Process/ Exposure	Product	Number of Samples	Number of Companies	Estimated Mean	95% C.I.	One S.D. Interval
Open/Direct	Boats	270	8	82	79-84	28-230
	Truck parts	23	2	61	40-92	21-171
	Tubs/showers	149	3	47	45-48	16-131
	Yachts	184	3	37	34-41	6-198
	Tanks/pipes	364	4	24	24-25	8-68
	Domes*	40	1	13	11-14	4-36
	Fans	2	1	5	3-10	1-13
Press/Direct	Auto/truck parts	214	2	26	22-31	8-70
	Electrical box	15	1	13	9-20	4-35
	Containers	55	2	13	12-14	4-35
	Trays	13	1	11	8-15	3-2[illegible]
	Forms	21	1	11	8-14	3-29
Open/Indirect	Boats	2	1	19	11-33	9-35
	Tanks/pipes	38	3	15	13-17	7-27
	Yachts	5	1	7	6-9	3-1[illegible]
	Tubs	7	1	3	1-5	1-5
Press/Indirect	Containers	12	1	9	7-12	4-16
	Trays	52	1	4	3-5	1-6
	Forms	20	1	5	4-8	2-9
		1486	38[1]			

[1]Two companies had both open- and press-mold processing. Processes were performed in separate buildings.

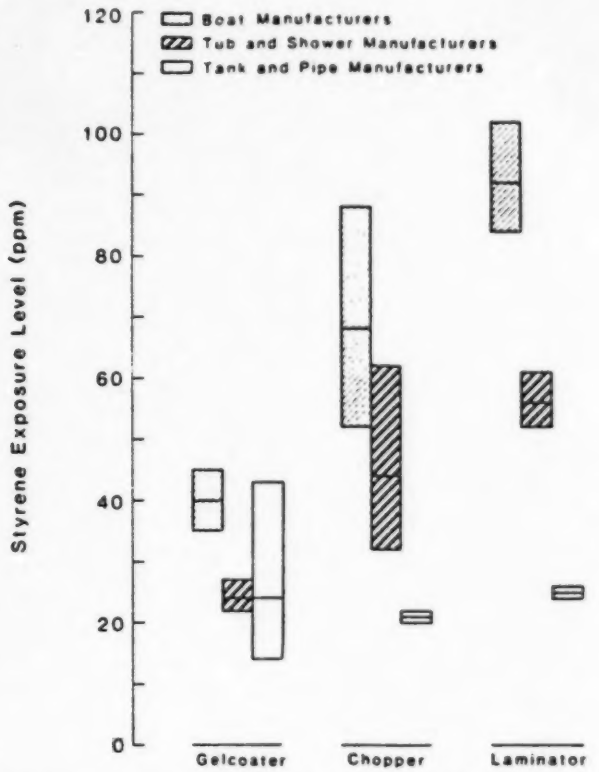

Figure 1—Mean styrene exposure levels and 95% confidence intervals by job title for three open-mold companies.

on the same day at the same company; the sampling date component was smaller, and the company-to-company component was zero in all but one category.

The differences in mean exposure values among product categories were greatest for the open-mold, directly-exposed category, ranging from 5 ppm for the production of fans to 82 ppm in the manufacture of boats (Table VI). Manufacturers of truck parts and boats had the highest exposures to styrene, 61 and 82 ppm, respectively. Surprisingly, yacht manufacturers had less than half the mean exposure of smaller boat companies. This difference might be explained geographically. The yacht companies were located in milder climates, where large garage-type doors were constantly open, perhaps improving air exchange and resulting in lower exposures. Furthermore, curing usually took place outdoors.

Within the open-mold, direct-exposure grouping, manufacturers of tanks, panels and fans had the lowest mean exposures, 5-21 ppm. These companies used fewer hand-held spray guns, resulting in reduced styrene vaporization. As exemplified by the standard deviation intervals, variation in individual exposure was particularly large for manufacturers of boats, truck parts, tubs and showers, and yachts.

Directly exposed workers at companies doing press molding had mean styrene exposures between 11 and 26 ppm. Workers with indirect contact with styrene in the open mold operations had mean exposures similar to that of directly exposed press molders.

Though the data were less complete for individual job titles, there was sufficient information to compare styrene levels for three job titles—gelcoaters, chopper gun operators and laminators—in the three open-mold product categories. Also styrene exposures for press-mold operators and mixers were compared for companies manufacturing auto/truck parts, containers and trays (Figures 1 and 2). There was considerable overlap in styrene exposure among job titles classified as direct exposure within open-or press-mold processors. Boat manufacturers had higher levels than did tub and tank manufacturers for each individual job title. Boat laminators, those individuals who smooth and roll out following spray-up, had the highest overall mean exposure at 92 ppm.

Discussion

Styrene exposures between and within press-mold job categories are stable and relatively low, averaging 26 ppm or less.

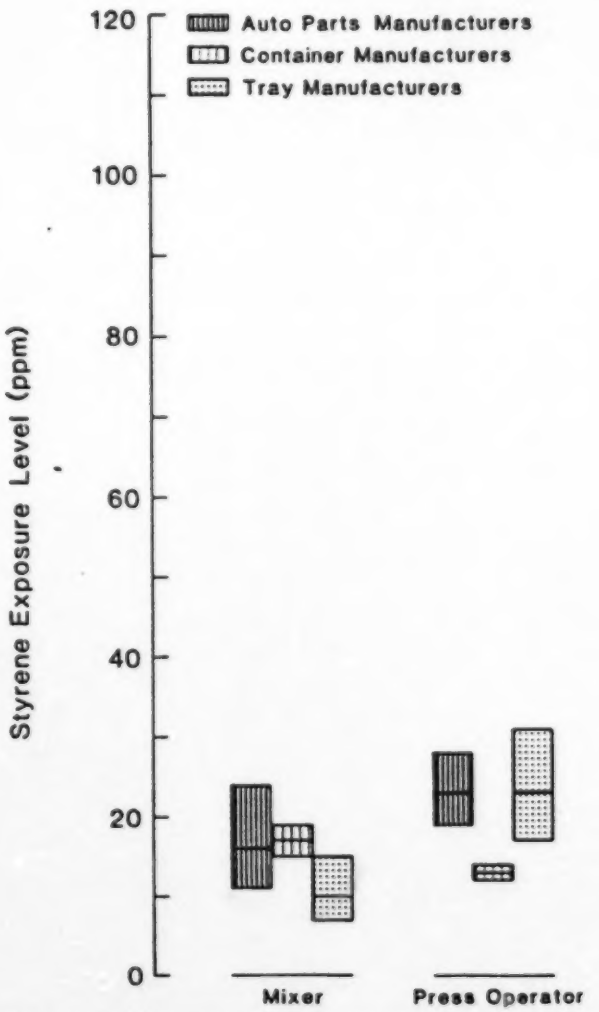

Figure 2—Mean styrene exposure levels and 95% confidence intervals by job title for three press-mold companies.

The variability between product categories for open-mold manufacturers is considerable, with small boat companies having the highest styrene exposure; fan, tank and panel manufacturers having the lowest. There were large standard deviation intervals about the mean for manufacturers of boats, truck parts, tubs and showers, and yachts. These large intervals suggest that a large portion of workers at these companies are receiving substantial exposure. On the other hand, the relatively lower styrene exposures found in the companies manufacturing tanks and pipes may indicate that exposures can be controlled.

The styrene exposure values reported in this study are comparable to those reported by others in similar industries. Schumacher, *et al.*[19] extensively studied 12 reinforced-plastics industries in Washington. In the boat-making industry the mean concentration for directly exposed jobs was 154 ppm. Other studies of boat companies have found mean levels for high-exposed jobs to range from 41 ppm to 102 ppm.[15,16] The 95% C.I. reported in this study of 79-84 ppm for boat manufacturers is well within this range.

Mean levels of styrene exposure in the manufacture of tubs and showers have been reported to vary between 40 and 100 ppm.[23,24] Other companies manufacturing truck parts, containers, enclosures and furniture had mean styrene exposures ranging from 9-60 ppm.[19,20] Thus, the styrene exposure data from this and other studies demonstrate that workers manufacturing boats, truck parts, and tubs and showers have the highest exposures. The similarities in exposure means from this study to those reported by other investigators lends credence to the use of retrospective exposure data for estimation of prior worker exposure. Hence, investigators attempting to assess exposures retrospectively should not overlook government sources.

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